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AEROSPACE ORGANIZATIONS IN BRAZIL AND COMPREHENSIVE DESCRIPTION OF THEIR PLANS

Xie Ping

ABSTRACT: This article details the major aerospace organizations in Brazil and their activities. Aerospace projects in Brazil are briefly outlined. Although these projects have been set for three decades, yet few people know about them. In this article, brief descriptions are made on the major tasks and the progress in Brazil's aerospace projects, as well as the difficulties and prospects.

Key Words: scientific research organizations, aerospace projects, spacecraft launch site, Brazil.

At present, there are four independent organizations in Brazil engaged in aerospace activities: the Research Academy of Aerospace Activities, Baleiladuyinfeinu [transliteration] Launch Center, A'erkantala [transliteration] Launch Center, and Space Research Academy under the Brazilian Ministry of Science and Technology. In addition, there is an Aerospace Activities Committee (COBAE) in Brazil, responsible for coordinating

activities of these above-mentioned organizations. The committee is subordinated under the Brazil State Safety Commission. The official in the Armed Forces Commission is the chairman of COBAE. He is responsible for proposing aerospace policies and planning to the president of Brazil. Since 1974, the COBAE committee has pursued a project, Brazil Aerospace Mission (MECB); the purpose of the project is to launch into space with rockets (made in Brazil) satellites (also made in Brazil) from a launch site in Brazil. In the early nineties, four satellites made under supervision of the Space Research Academy will be launched into space from a newly-built A'erkantala Launch Site with carrier developed by the Research Academy of Aerospace Activities.

Brazil Research Academy of Aerospace Activities (IAE)

IAE is the main department for carrying out aerospace projects in Brazil. IAE is responsible for rocket development; actually, it is a research academy under the Spaceflight Technology Center (CAT). CAT is Brazil's number one research academy, managed by the Air Force and located in San Jose dos Campos located 97km northeast of Sao Paulo. Under CAT, there are several research institutes.

Since the aerospace projects have been set in Brazil, IAE is responsible consistently to study the carriers. The research academy has built a series of solid-fuel rockets named Sonda (refer to Table 1). There are two stages of development of the Sonda series rockets. In the first stage, IAE fabricated a

simple space probe rocket series: Sonda-1, -2, and -3, with tail fin stabilization. Recently, IAE developed a model of a three-axis stabilized control system, which can control the rocket to fly in the predetermined trajectory. Until the present time, only Sonda-4 adopts this stabilized control system.

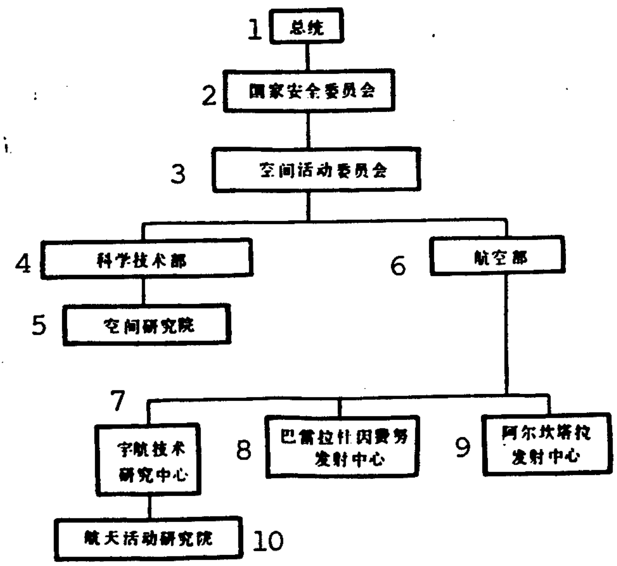

Fig. 1. Aerospace organizations in Brazil
KEY: 1 - president 2 - National Safety Commission 3 - Space Activities Commission 4 - Ministry of Science and Technology 5 - Space Research Academy 6- Ministry of Aviation 7 - Spaceflight Technology Research Center 8 - Baleiladuyinfeinu Launch Center 9 - A'erkantala Launch Center 10 - Aerospace Activities Research Academy

The first Sonda-1 of IAE took part in the experimental international project on atmospheric research in 1966. Sonda-2 is a single-stage rocket. At present, three versions of Sonda-2 were built: Sonda-2, Sonda-2-B, and Sonda-2-C. More than 50 launches were carried out by these versions. At present, IAE applies Sonda-2 as the experimental rocket for new propellants,

aerodynamic design, and electronic components. The Sonda-3 rocket uses the engine of Sonda-2 as its upper-stage engine. This is Brazil's all-instrumented rocket by adopting the first-stage separation system, the second-stage ignition system, as well as the advanced systems of flight data recording system,

TABLE 1. Sonda Series Rockets

1 型号	试验发射日期(年) 2	飞行高度(公里) 3	有效载荷(公斤) 4
Sonda 1	1966	60~70	4.2
Sonda 2	1967	100	44
Sonda 3	1976	500	50
Sonda 4	1984	(不详) 5	(不详) 5

KEY: 1 - model number 2 - experimental launch date (year)
3 - flight altitude (km) 4 - payload (kg) 5 - not known

attitude control system, and payload recovery. To adapt to the demand of ever-increasing aerospace tasks, later improved versions of Sonda-3 were developed in Brazil. This rocket can carry 130 to 160kg of payload, but an altitude of 500km is still beyond reach. Beginning in 1976 with the launch of the first prototype of Sonda-3, altogether 23 launches of this rocket model have been carried out.

The Sonda-4 rocket began development in 1975; this is Brazil's second-generation rocket. Sonda-1, -2, and -3 are free-flight rockets, but Sonda-4 adopts for the first time the new three-axis stabilization control system. Sonda-4 is a two-stage rocket; the S-20 engine (the rocket engine used in the Sonda-3 first stage) is installed in the second stage of Sonda-4, which

carried out launch experiments in November 1984, November 1985, October 1987, and April 1989. During an experiment in October 1987, separation between the first and second rocket stages failed, so that the launch time was delayed for the succeeding

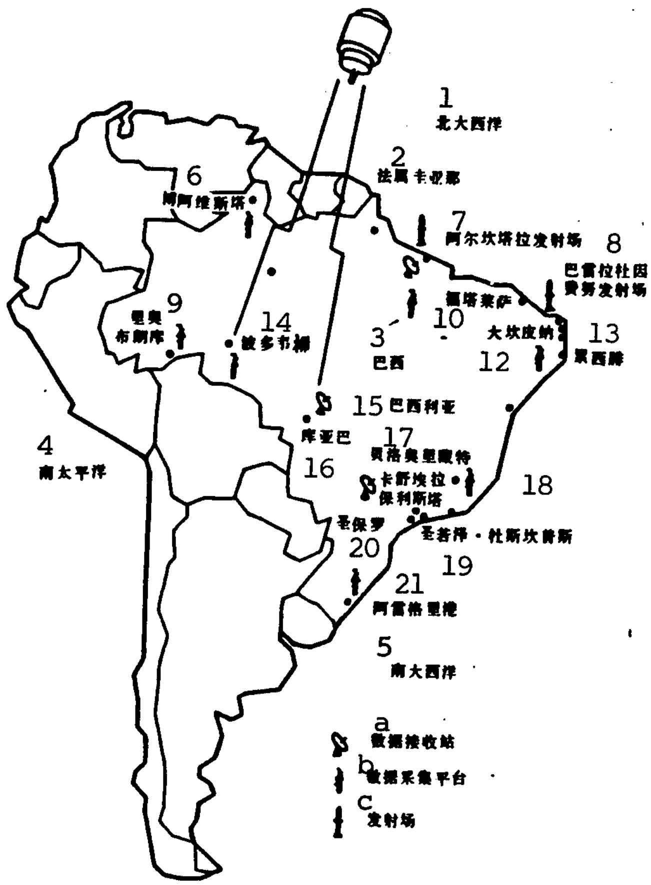

Fig. 2. Map of aerospace facilities and organizations in Brazil
KEY: a - data receiving stations b - data collection platforms
c - launch site 1 - No. Atlantic 2 - Fr. Guyana 3 - Brazil
4 - So. Pacific 5 - So. Atlantic 6 - Boa Vista
7 - A'erkantala Launch Site 8 - Baleiladuyinfeinu Launch Site
9 - Rio Branco 10 - Fortaleza 11 - [not used] 12 - Campina Grande 13 - Recife 14 - Porto Velho 15 - Brasilia
16 - Cuiaba 17 - Belo Horizonte 18 - Kashuaila Baolisita
19 - San Jose Dos Campos 20 - Sao Paulo 21 - Porto Alegre

Sonda-4. Sonda-4 was planned in Brazil to develop into a carrier for satellites (VLS); however, the project was delayed and

delayed, unable to be accomplished on schedule.

Baleiladuyinfeinu (CLBI) and A'erkantala (CIA) Launch Centers

The IAE is responsible for the development of rockets in Brazil. The application authority for rockets is another organization, Baleiladuyinfeinu (CLBI) Launch Center, under COBAE. This launch center is situated in the northeast coast of Brazil, 19.4km^2 in size, 12km from Natal. The launch site was built in 1965; this is the launch site of intermediate and early-stage space probe rockets in Brazil's aerospace projects. The launch site is close to the equator and the Atlantic Ocean, with many cloudless days. The first group of technicians of CLBI was trained in the United States. Based on an agreement between these two nations, first, Brazil's technicians receive training in the United States. Then, the United States dispatches personnel to Natal to teach Brazilians methods of applying American equipment. The time of the inauguration of the CLBI Launch Center was December 1965. The launch site is still operating today.

Besides the CLBI Launch Site, Brazil is building its second launch site at A'erkantala. The decision to build this launch site was made in 1974 by COBAE with the principal reason being that the CLBI launch facilities were unable to meet the demand for six launches per year by MECB. Moreover, the launch site did not have sufficient land for expansion.

The CLA Launch Site is situated on the Atlantic coast of northeast Brazil, with the size of 520km^2. This location was

selected in September 1980. Here the climatic conditions are excellent, with sunny days. Wind force within a small range can be expected with comparatively stable temperatures. The biggest advantage is its location at $2^{0}24'$ S. Lat., and $44^{0}25'$ W. Long., near the equator. This is an ideal launch site for geostationary satellites.

Brazilian Space Research Academy (INPE)

Differing from the IAE, the INPE is a nonmilitary unit, responsible for fundamental and applied research on peaceful uses of space. There are seven administrative bureaus under INPE, including a meteorological bureau, engineering and space technology bureau, remote sensing bureau, as well as a space sciences and atmospheric bureau.

The headquarters of INPE is at the same location of CAT in San Jose Dos Campos. The site adjoins IAE. Most of the research at INPE is conducted at San Jose. In addition, the INPE is responsible for administering several remote sensing stations and receiving stations throughout Brazil, including ionospheric research stations at Kashuaila Baolisita and Fortaleza, a radio observation station at Adibaya, a Landsat receiving station at Cuiaba, and a regional remote sensing laboratory at Campina Grande.

The INPE enjoys a certain reputation in the international aerospace field. In 1986, the INPE sponsored the Latin American Remote Sensing Symposium; delegates from the United States,

France, Germany, the U.K., and Japan attended the consortium. The INPE also has the resources to take part in bilateral research and training projects. For example, it took part in research in tropospheric chemical properties over the Amazon Valley as initiated by NASA. INPE engineering and technical personnel signed a cooperative training agreement with the Ministry of Communications of Canada. Recently, the INPE reached an agreement for cooperation in scientific research with the Soviet Union regarding oceanography, geophysics, and atmospheric physics. Additionally, China will cooperate with INPE to build remote sensing satellites (SSR).

Aerospace Activities in Brazil (MECB)

As mentioned above, the MECB is a project to send Brazil-made satellites into space. The initial plan is to send two Brazilian data collecting satellites (SCD) into equatorial orbit (orbital altitude at 750km) in 1989 and 1991. Then in 1993, two remote sensing satellites will be sent into orbits between 300 and 550km. COBAE considers that the MECB is its principal project under its leadership. The INPE is responsible for developing and building ground support, tracking and control facilities related to satellites. The IAE is responsible for designing the carrier rockets. The task of building the A'erkantala launch facilities is charged to the execution team (GICLA) at the CLA Launch Center recently formed. Table 2 shows the MECB budget and its actual expenditures.

In the MECB project, INPE is responsible for most tasks. One-half of the INPE budget is used in the MECB project. Four data collection satellites (SCD) (refer to this publication, No. 6, 1991) will be built with cooperation from Brazil industries. The first satellites SCD-1 and SCD-2 are used to receive and relay meteorological and hydrological data from various ground data collection stations. These unattended ground stations have sent environmental data, wind speed, temperature, humidity, and rainfall to the GEOS satellites of the United States since the late seventies. The SCD-1 (applying approximately 50% of technology in Brazil) will be built in the near future. However, the SCD-2 is still in the development stage. Both the SSR-1 and SSR-2 are in the development stage; both satellites will be launched in 1993 or later years.

TABLE 2. MECB Budget and Actual Expenditures
(in 100 millions of U.S. dollars)

执行机构 1	项 目 2	计划开支(1982~1992年)	实际开支(1982~1988年)
IAE	LVS	3 2.83	4 1.55
CLA	阿尔坎塔拉发射设施 5	2.83	0.538
INPE 6	卫星制造(SCD-1和2. SSR-1和2)	2.84	1.83
7 总计		8.50	3.918

KEY: 1 - executive organization 2 - project 3 - planned expenditures (1982 to 1992) 4 - actual expenditures (1982 to 1988) 5 - A'erkantala Launch Site 6 - building of satellites (SCD-1, and SCD-2, as well as SSR-1 and SSR-2) 7 - total

To smoothly proceed with the development of SSR and SCD satellites, the INPE has to expand its fundamental facilities. One of these tasks is to build a space environmental simulation facility. In December 1987, the laboratory of satellite assembly and testing was completed; the laboratory can simulate space

environments of oscillation, impulse, electromagnetic interference, and temperature in vacuo. Moreover, with this space environmental simulation facility, INPE can inspect the functions of satellite design and satellite assembly systems.

Another expansion task of INPE is surveying and control equipment on board satellites. At present, near the INPE headquarters at San Jose Dos Campos, an MECB task control center is being built. It is planned to build SCD-1 and SCD-2 data receiving stations at Cuiaba and the CLA Launch Site, and a collection and distribution center for remote sensing imagery to be built at Kashuaila Baolisita.

The IAE will develop a carrier rocket (VLS) for MECB. In the concept, VLS is a four-stage rocket, capable of sending satellites of 100 to 200kg into an orbit between 250 and 1000km. The first three stages of the rocket employ a three-axis stabilization control system; the fourth stage applies spin-stabilization. There is an inertial platform and a satellite-borne computer in the fourth stage. Most remote sensing equipment, transponders, and antennas are installed in the fourth stage.

Progress in MECB Project

In the first years, the MECB project progressed smoothly. Later, since the technical difficulties were encountered in the development of VLS, the entire project was much delayed. For example, in December 1985, the one-third reduced scale model VLS-

R1 failed in flight tests because ignition failed in the turbine engine. In October 1987, the satellite-borne computer malfunctioned, and the first and second rocket stages were unable to be separated, thus, the experimental launch of Sonda-4 rocket aborted. These failures delayed the succeeding Sonda-4 launch date from october 1988 to April 1989.

There are some nontechnical problems with the launch delay of Sonda-4. IAE applied to import from the United States the digital inertial altimeters used in Sonda; difficulties were encountered in the application for U.S. exports. Four months must be waited before the United States issued a temporary export license.

Comparatively speaking, the development of the SCD-1 satellite of INPE progressed relatively smoothly. However, due to incomplete considerations, development dates of the satellite rocket were contradictory, leading to difficulties between the Ministry of Science and Technology (MCT) and the Ministry of Aviation. Both MCT and the INPE had the view that MECB should apply foreign-made rockets to launch the SCD-1 satellite in June 1991. A U.S. Scout rocket, a French Ariane, or a Chengzheng carrier of China, can be considered in priority fashion. In their view, the delay of the SCD-1 launch will add to the economic burden on the INPE because of penalty in not carrying out the contract. Opponents were mainly military personnel in the Ministry of Aviation. They thought the entire MECB project should wait until the completion of VLS.

Other than the technical problems and the internal contradictions, due to a lack of funds in recent years, progress in several of the above-mentioned fundamental facilities affected. Limited appropriations from the Brazilian government also affect the personnel training program. In 1986, 143 technical personnel of IAE resigned to take private jobs because of low government wages.

There are many problems in the aerospace program of Brazil. All projects funded by the government do not have secure sources of appropriations. The new administration of Brazil following the election is very possibly to reduce investments in aerospace programs because of the difficult problems of controlling the federal budget deficit in considering the MECB investments. The MECB program will be continuously delayed. Like other third-world countries attempting to develop their national aerospace industry, Brazil also confronts many technical difficulties, especially carrier rocket technology, because developed countries limit the technical transmission. Therefore, Brazil is unable to acquire these technologies from the open market. Without these technologies, the targets of the MECB are unable to be attained. The financial and technical difficulties control Brazil's aerospace program will lead to drastic cuts in such programs and targets.

APPLICATION AND RESEARCH STATUS OF AEROSPACE COMPOSITE MATERIALS AND THEIR PROSPECTS

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Composite materials have found wide application in aero–space industry. In this paper, the present status and prospect of applied research on composite materials for aero–space application in China are given. Repair technology, property testing techniques at high and low temperature, characterization and quality control as well as applied basic research of composite materials are also briefly introduced.

Key Words: composite materials, aerospace materials, composite materials technology, repair technique, performance test, quality control, aerospace technology, China.

Composite materials have a number of advantages, with unique significance to aerospace industry. As indicated by practical experience in China and abroad, the high-level composite materials have decisive functions in upgrading spacecraft quality, increasing payload, and upgrading tactical performance indicators. The new-generation spacecraft require further miniaturization, weight reduction, and high performance. Therefore, applications of high-level composite materials have a

key influence. As to the status of composite materials used in aerospace abroad, large numbers of reference materials were reported. The article will present mainly the application and research status of aerospace composite material in China and their future prospects. It is expected to be helpful to the development of aerospace composite materials in China.

I. General Situation with Application and Research on Aerospace Composite Materials

The application and research status of high-level composite materials in aerospace industry can be classified into four divisions:

1. The problem of thermal protection of reentry vehicles can be completely solved. Gigantic achievements have been obtained in research on heat-resistant composite materials. Research on heat-resistant composite materials at different locations and of different types has passed through two, three, and four generations. For example, the heat-resistant composite material used in a reentry vehicle nose cone has passed through the four generations of glass fiber composite materials, high-silica-fiber composite material, a ceramic-based composite material, and triaxial carbon/carbon composite material. Today it is the research stage for the fifth generation.

2. Applications of structural composite materials have grown more and more in spacecraft, developing toward large structural members and such members as are under the main bearing load, thus, attaining significant effectiveness in reducing the

spacecraft mass. For example, the front and rear cylindrical

TABLE. Some Structural Members Made of Composite Materials in Spacecraft

1 序号	名称 2	3 说明	备注 4
1	卫星接口支架 a	锥形结构，上端 Φ1664mm，下端 Φ2042mm，高 300mm，蒙皮厚 1.8mm (图 1) l	与等结构铝合金接口支架比，质量减少 40% x
2	整流罩前锥 b	玻璃钢蜂窝夹层结构(图 2) m	用于长征二号 E 和长征三号 y
3	整流罩柱段 c	无孔耐久铝蜂窝，Φ4.2m × 1.5m 和 Φ4.2m × 3m n	用于长征二号 E z
		有孔铝蜂窝 o	用于长征三号 a'
4	整流罩倒锥 d	无孔耐久铝蜂窝，Φ3.38m × Φ4.2m × 1.34m p	用于长征二号 E b'
5 e	卫星消旋天线支撑筒	代替铝合金支撑筒 q	比铝合金支撑筒质量减少 50%以上 c'
6	外加筋壳 f	外径 450mm，高 850mm，质量 6.6kg，轴压试验载荷近 600kN r	代替铝合金后质量减少 30% d'
7 g	内加筋壳	外径 450mm，高 850mm，质量 5.5kg，轴压试验载荷达 650kN s	代替铝合金后质量减少 30% e'
8 h	水平梁	外形尺寸 964mm × 580mm，由变截面、变厚度的"I"、"Γ"和"T"字型梁组合的复合梁 t	比镁铝件质量减少 50% f'
9 i	四桁加筋板	长 500mm，宽 426mm，蒙皮厚 1.31mm，重 0.938kg，平均轴压破坏载荷 109kN u	比铝合金加筋板质量减少 30% g'
10 j	喇叭天线	热稳定性好，电信号损失小 v	用于同步试验通信卫星 h'
11 k	加筋锥壳	由三角形网格整体加筋(由两向斜筋和环向筋组成)，外蒙皮和上、下端框组成。整体刚度优良，结构稳定性好，体积效率高，可大大减小结构质量 w	用于航天飞行器的头部和弹体的壳体结构 i'

KEY: 1 - Number 2 - Name 3 - Explanations 4 - Remarks
a - satellite connectors b - front cone of fairing
c - cylindrical section of fairing d - inverted cone of fairing
e - satellite despin antenna support cylinder f - external ribbed shell g - internal ribbed shell h - horizontal blade
i - four-girder ribbed plate j - horn antenna k - ribbed cone shell l -conical structure, upper end OD1664mm, lower end OD2042mm; 300mm high; 1.8mm thickness of covering fabric (Fig. 1)
m - reinforced plastic honeycomb sandwich structure (Fig. 2)
n - durable aluminum honeycomb without holes, OD4.2m x 1.5m and OD4.2 x 3m o - aluminum honeycomb with holes p - durable aluminum honeycomb without holes, OD3.38m x OD4.2m x 1.34m
q - substitute aluminum alloy support cylinder r - 450mm for

external diameter, 850mm high, 6.6kg mass, and nearly 600kN for axial pressure test loading s - 450mm external diameter, 850mm high, 5.5kg mass, and 650kN for test loading of axial pressure t - external dimensions 964mm x 580mm. This is a composite beam composed of the variable cross-section and variable thickness I-, L-, and T-shaped beams u - 500mm long, 526mm thick, thickness of covering fabric 1.31mm, and 0.938kg in weight. The average axial pressure in destructive loading is 109kN v - good thermal stability and small loss of electrical signal w - composed of triangular-lattice ribbing (composed of two-dimensional oblique ribs and annular ribs), outer covering fabric as well as frames at upper and lower ends, with good rigidity, good structural stability, high volumetric efficiency, capable of greatly reducing structural mass x - compared with the aluminum alloy conductor of the same structure, the mass is reduced by 40% y - used in Chengzheng 2E and Chengzheng 3 z - used in Chengzheng 2E a' - used in Chengzheng 3 b' - used in Chengzheng 2E c' - reduction by more than 50% in mass compared to aluminum alloy support cylinder d' - the mass is reduced after aluminum alloy is used as replacement e' - mass is reduced by 30% after aluminum alloy is used as replacement f' - mass is reduced by 50% compared to nickel-aluminum piece g' - mass is reduced by 30% compared to aluminum alloy ribbed plate h' - used in synchronous experimental communications satellite i' - used in nose cone of spacecraft, and shell structure of missile body

sections of rocket fairings for Chengzheng 2E are holeless endurance aluminum honeycomb structure, with dimensions OD4.2m x 1.5m, and OD4.2m x 3.0m. The satellite joint support is made of carbon/epoxy composite material; the dimensions at the upper terminal are OD1664mm, and at the lower terminal--2042mm, with 300mm in height. Compared to the equal-structure aluminum alloy joint support, the mass is reduced by 40%. Table 1 shows the composite material members for the structure of the spacecraft.

3. There has been much progress in research on functional composite materials. Good advances were gained in wave-absorbing stealth status, nuclear-blast-resistant reinforcements, and resistance to particle clouds. Research has also been advanced

in composite materials of dual or multiple functions, such as

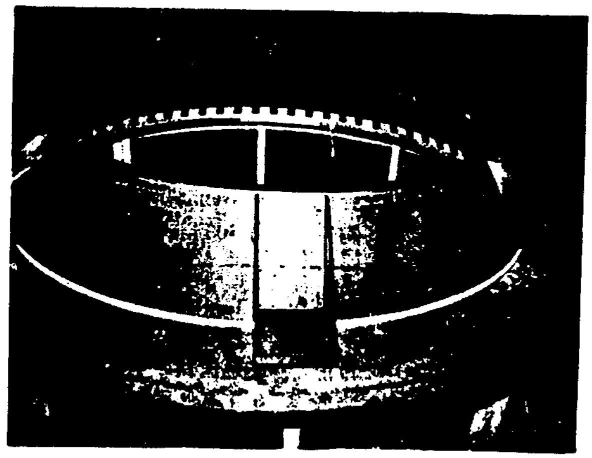

Fig. 1. Satellite connector support

structure/thermal resistance, structure/stealth status, thermal resistance/reinforcement against nuclear blasts, structure/thermal resistance/reinforcement against nuclear blast, and structure/thermal resistance/stealth status. These advances set up the conditions for applications of new generation spacecraft.

4. Much activity has been carried out on research of ceramic-based, metal-based, carbon-based, and resin-based composite materials, thus laying the foundation for developing high-tech aerospace.

II. Repair Techniques for Composite-Material Structural Members

An important route to applied research on composite materials for aerospace includes the defects in aerospace

composite materials, as well as healing over of damage and repair of structural members. Since more and more structural members are made of composite materials in spacecraft, defects may occur while manufacturing, storing, transporting, and application, or damage occurs due to collisions, in order to ensure quality and reliability in reducing cost and losses; it is required to develop repair techniques for members for these defective or damaged members.

After x-raying and ultrasonic inspection of fairings, it was discovered that the joint honeycomb had parted and adherence between plates was defective, in addition to collision damage due to accidents in the operating process; we developed three formulas for repair materials and the corresponding repair techniques for types G7A-5 and G7A-9, based on the demands of the design division. For example, type G7A-5 repair material can be injected under pressure, resulting in sufficient operational service life. Solidification can be carried out at room temperature and constant pressure. After solidification, the mechanical properties of the repair materials satisfy the design demand, with density lowered by 40% compared to the epoxy resin extrusion. The linear contraction rate of the solidified piece is only one-half to one-third of the epoxy resin that has the lowest shrinkage rate among the thermosetting resins.

To verify the performance indicators after repairing the damaged structural members, simulation tests under lateral pressure were conducted. The dimensions of the simulation member

are 250mm x 250mm x 4mm. There is artificially caused damage to

Fig. 2. Reinforced plastic honeycomb lamination structure used in front cone of fairing for Chengzheng 2E

the member. After repairing with type G7A-9 repair material with a specific technique, loading tests were conducted. Both terminals of the loading were reinforced by reinforced plastics. Based on the design requirements, the simulated member should fail after loading to 19.61 to 29.42kN. In the test results, the failure of the member occurred when loaded to 54.3kN. Destruction occurred near the reinforced site of the reinforced plastics. There were no destructive signs at the damage repair site, and its vicinity.

In a honeycomb sandwich structural member, upon damage inspection, seven different sizes of assembled honeycomb were

discovered to have separated. The maximum length of separation was 350mm, and the widest location is about 40mm. Generally, the dimensions are about 100 x 20 x 40mm. After using type G7A-5 repair material for repair, static tests were conducted to inspect the repair quality and reliability of the members. During the inspection, no damage occurred to the repaired member when the load was up to 1.569kN, thus completely satisfying the design and application requirements. As indicated by facts, the special repair technique of aerospace composite material members is an important technique, which brings gigantic social and economic benefits to the aerospace industry.

III. Inspection Tests on High and Low-temperature Properties of Composite Materials

In the development of aerospace technology, it is required to determine the properties of the material in specific environments. An analysis of tests of high- and low-temperature properties of the material is an important aspect. When a reentry spacecraft reenters the atmosphere, its speed may exceed Mach20, its temperature can reach thousands of degrees centigrade, pressure may exceed 100atm (approximately 10MPa), thermal currents as high as 10 to hundreds of thousands of kJ/m^2 per second, and overload may exceed 100g. High-level composite materials are the key to solving the problem of survivability of missiles under these rigorous conditions. However, research on high-level composite materials should first solve the problems of tests for performance at high temperatures. For example, with

respect to high-level carbon/carbon composite materials, it is required to solve the problem of analyzing the high-temperature property tests of over 2000°C. The carrier rocket for launching communication satellites employs an oxyhydrogen engine as the first stage. Such engine is fueled with liquid hydrogen or liquid oxygen at very low temperatures; the properties of materials at such low temperatures are the key as to whether or not such material can be selected. Therefore, we should solve the problem of testing composite materials in such ultralow temperatures.

After systems research, we successfully solved the problem of testing the high- and low-temperature performance of aerospace composite materials, with the development of the corresponding equipment and prescribing the related standards. The high-temperature performance indicators of aerospace composite materials required for testing include mechanical properties, thermal conductivity coefficient, average linear expansion coefficient, specific gravity, and elasticity constants. The applied high-temperature performance test methods include heating with electric conduction, noncontact measuring strain method (measuring mechanical properties for room temperature to 2400°C), laser pulse method (measurement of heat conduction coefficient from room temperature to 2500°C), quartz difference indication method and laser scanning method (measuring the mean linear expansion coefficient from room temperature to 900°C, and from 1000 to 2500°C), adiabatic copper calorimeter method (measuring

specific heat from room temperature to 2900°C), and tungsten chain hanging resonance method (measuring elasticity constants from room temperature to 2900°C). By using these high-temperature performance test techniques, we have measured all sets of high-temperature performance data for high-level carbon/carbon composite materials, including strength, modulus, cracking strain, expansion coefficient, heat conduction coefficient, specific heat and thermal radiation coefficient. These parameters were provided to design offices for analysis and design with thermal stress, thus making a contribution to the development of new-generation models.

The low-temperature performance of aerospace composite materials requiring testing includes mechanical properties, coefficient of thermal conductivity, average linear expansion coefficient, specific heat, and elasticity constant. The applied methods include the multispecimen soaking method (measuring the mechanical properties between 20 and 300K), laser pulse method, and longitudinal-direction heat current stabilization method (measuring the thermal conductivity coefficient), quartz difference indication method (measuring the average linear expansion coefficient), vacuum adiabatic calorimetric method (measuring specific heat), and dynamic method (measuring the elasticity constant).

IV. Control of Performance Attributes and Quality

Control of performance attributes and quality of composite

materials and their raw materials is consistently the key to promoting the applications of composite materials in the aerospace industry. How to ensure the high quality of structural members made of aerospace composite materials involves ensuring their performance and repeatability (small divergence coefficient of performance). Quality stabilization and application reliability are consistently highly regarded. This is a central task in research on aerospace composite materials.

Control of the attributes and qualities of matrix resin used in composite materials has been consistently stressed since the seventies. At the NASA Langley Research Center, systematic development of quality control tasks with graphite fibers for reinforcement of epoxy resin composite materials has been carried out. The purpose was to study the methods of performance indication, test analysis, and quality control in order to ensure the repeatability, stabilization, and reliability of composite materials. A large amount of work was done on performance indicators and quality control by the U.S. Air Forces Materials Laboratory, Naval Ground Weapons Center, Naval Research Laboratories, Army Materials and Mechanical Center, Lockheed Corporation, McDonnell-Douglas Corporation, Namco Materials Corporation, and Shiva Corporation, with great success.

We conducted systematic and feature-oriented analytical studies on matrix resins of different types, different grades, and different lot numbers made by different manufacturers in more than 60 aerospace composite materials in China. The most

advanced test analytical methods were used, including highly effective liquid-phase spectra, gel spectra, Fourier transform infrared spectra, difference-indicating scanning heat measurement and analysis, thermogravimetric analysis, and nuclear magnetic resonance spectra. We studied the relationships among structures, constituents, and performance of the matrix resins. As indicated in the research results, the general performance indicators of epoxy resins are six items: epoxy value, epoxy equivalent weight, viscosity, volatile matters, organochlorine content, and inorganic chlorine content. However, we still were not able to reveal and control the quality of the matrix resin for high-level aerospace composite materials nor to ensure the repeatability, quality stabilization, and application reliability of such composite materials. Therefore, we should focus on different resin systems to study the key parameters and the allowable fluctuation range for quality control. The highly effective liquid-phase spectrograms and infrared spectrograms are used to control the performance peaks, indicated in "fingerprint" form. On this basis, we prescribe five standards in the method indicting epoxy resins, as follows:

1. DSC method of determining the solidification of epoxy resins;

2. Thermogravimetric analysis of epoxy resins;

3. Determination method for infrared indicators of epoxy resins;

4. Analytical method of highly-effective liquid-phase

spectrograms; and

5. H-nuclear magnetic resonance analytical method.

In quality control of structural members made of aerospace composite materials, as to the requirements and specific features of quality of members made of composite materials in spacecraft, we studied and established the five following methods in the quality warranty systems and techniques:

1. X-ray flaw detection technique to detect various flaws of structural members made of composite materials;

2. Ultrasonic flaw detection, to detect various flaws in a material, especially deadherence and delamination, as well as the determination of inclusions content and fiber inclusions;

3. Acoustic emission technique to simulate the dynamic performance in actual workload in order to predict the status of structural members under workload;

4. Laser holographic technique is used in quality inspection and control of specific structures; and

5. C-scan technique to determine dimensions and special positions of flaws.

These nondestructive inspection techniques are on the leading-edge in China. In some respects, some of them have attained an advanced international level, with very important functions in ensuring the quality of structural materials made of aerospace composite materials.

V. Fundamental Studies on Applications of Aerospace Composite Materials

Fundamental studies on applications of aerospace composite materials are a vital integral part of applications research on such materials, with important functions in applications of such materials. Therefore, emphasis should be placed thereon. In this respect, we mainly developed the eight following lines of study.

1. Analysis of malfunctions of structural members made of aerospace composite materials;

2. Analysis of ablation and erosion for eroded composite materials;

3. Relationship among defects, damage, and mechanical properties of composite materials;

4. Relationship between microscopic structure and performance of composite materials;

5. Study of crack damage and boundary surface of composite materials;

6. Route to obtaining reliability values of mechanical properties of composite materials, and to acquire mechanical performance indicators of materials with respect to the allowable design value;

7. Relationship among constituents, structures, and performance indicators of matrix resins in composite materials; and

8. Analysis of performance indicators and inspection of composite materials in a specific simulated special environment.

All these fundamental studies of applications have very

significant meaning in clarifying the regime, upgrading the quality, solving difficult problems, and expanding applications. For example, after dynamic ablation of a triaxial fabric of carbon/carbon composite material structural member, ablation grooves penetrating the surface appeared. With X-ray detection, this is a fan-shaped crack groove (about 50mm deep, and the maximum length is 40mm); however, in results from malfunctional analysis, the possibility due to the thermal stresses during ablation to form the crack groove was proven out. It was verified that there was no expansion of such crack grooves during the manufacturing process; therefore, this is an accidental case, thus providing a reliable basis for the decision-makers. As another example in the process of studying the relationship between microscopic structure and performance of carbon/carbon composite material, it is known that the spheroidal carbon structure has a great effect on the performance of carbon/carbon composite material. Its ablation, erosion, and crack damage are closely related to the spheroidal carbon content. Therefore, to achieve high-performance carbon/carbon composite material, we should design a control technique to avoid spheroidal carbon structure from forming. This points to a direction for the development of high-performance carbon/carbon composite material. Another example: when the acoustic emission technique was used to monitor the dynamic process damage, it was discovered that the generation and buildup of damage are continually not at the flaw sites in the static state, as frequently the boundary surface is

the weakest sector. Therefore, when inspecting the performance and quality of structural members made of aerospace composite materials, it is insufficient to inspect only the static flaws of the member, we should study the damage source and the variation trends of the member in the ablation environment, to study the relationship between damage and boundary surface with respect to the structure and performance of the material, in order to study the overall evaluation method for the member. Thus, whether or not the product is qualified can be more scientifically determined.

VI. Prospects

The applications of high-level composite materials in aerospace industry are more and more extensive with the development of new model numbers of such materials. Briefly, the following points can be included with respect to the future development prospects of aerospace composite materials:

1. In the development of aerospace technology, it is required that models should be further miniaturized and lighter in weight, with higher performance. Therefore, the application ratios of high-level composite materials are continuously increasing in strategic missiles, tactical missiles, carrier rockets, solid-fuel rocket engines, and satellites.

2. With the actual situation in China, applications research into high-level composite materials in China's aerospace industry should follow the principle of closely combining with model

numbers and based on demand-pulled, as well as on the limited goal with key points.

3. By referring to development demand for model numbers, we have to engage key application studies on high-performance fiber composite materials, high-temperature-resistance matrix composite materials, high-level carbon/carbon composite materials, and multifunctional composite materials.

4. To further emphasize the analytical study of performance testing of the performance indicators of composite materials and their raw materials, the quality control as well as performance tests under specific conditions.

5. Further mechanization and microcomputer applications should be carried out in the manufacturing and processing techniques for structural members made of aerospace composite materials, and further expansion of the CAD/CAM (computer-aided design/computer-aided manufacturing) techniques.

6. Emphasize and highly regard the fundamental studies for application of aerospace composite materials.

7. Fulfill and improve the program centering on aerospace composite materials.

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